TRANSLATION

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Specification

Piezo Actuator Comprising A Structured External Electrode

The invention relates to an electrical multi-layer component, in particular a piezo actuator. In addition, the invention relates to a method for producing such an electrical multi-layer component.

Piezo actuators are known that have a base body, with a stack of stratified ceramic layers, and internal electrodes lying between them. The internal electrodes are made from a mixture of silver and palladium. The ceramic layers contain a ceramic based on lead zirconium titanate, which has a piezoelectric effect because of its ferroelectric properties. Because of the piezoelectric effect, the ceramic expands when electrical potential is present, so that it is possible to make actuators from such a multi-layer ceramic.

Also present in the known piezo actuators are outer electrodes, which are applied continuously to one lateral face of the base body and contact the internal electrodes.

In order to reduce the costs of producing the piezo actuators, an effort is made to replace the material of the internal electrodes and the material of the outer electrode with copper. In known piezo actuators, the outer electrode has the form of a continuous layer.

This form of the outer electrode is not suitable for outer electrodes made of copper. Under thermal demands, which occur, for example, when contact elements are soldered onto the outer electrode, with a continuous layer there is a shearing force between the outer electrode and the base body of the piezo actuator, which leads to damage to the boundary layer between the outer electrode and the base body.

This damage to the boundary layer is accompanied by a reduction of the effective bonding area between the outer electrode and the base body.

A piezo actuator produced in this manner is subjected, in the course of its use, to a multitude of mechanical strains, which in turn lead to shearing forces between the base body and the outer electrode. Because of the relatively high strength of the copper electrode, these additional loads result in the damage that arises when the thermal load spreads across the surface of the boundary layer and leads to detachment of the outer electrode. Thus the piezo actuator fails and can no longer be used.

The object of the present invention is to provide an electrical multi-layer component and a method for producing it, where the danger of detachment of the outer electrode is reduced.

This problem is solved by an electrical multi-layer component as recited in claim 1, as well as by a method for producing it as recited in claim 14. The other claims refer to advantageous embodiments of the invention.

An electrical multi-layer component is specified that includes a base body. The base body contains a stack of stratified ceramic layers, and internal electrodes lying between them. An outer electrode is placed on one lateral face of the base body, for contacting internal electrodes.

The outer electrode has the form of a layer in which at least one indentation is provided.

At the place of the indentation, the thickness of the layer can be reduced. That results in an intended tear point at this location, at which the tensile and compressive strength of the layer or outer electrode is reduced. As a result, even relatively small shearing forces of the outer electrode against the base body are sufficient to produce a tear through the layer at the intended tear point. As a result, the shearing load acting on the entire layer can be significantly reduced, since the tensile and compressive forces that produce the shearing load along the layer or along the surface of the base body can only add up over a correspondingly shortened distance.

In particular, the layer can have a local minimum thickness at the location of the indentations.

In just the same way, however, it is also possible to design the indentation in the outer electrode in such a way that the outer electrode is interrupted at the location of the indentation. As a result, in a sense a tear is provided already when the outer electrode is produced, so that it is inherently impossible for great shear forces to result from addition of tensile and compressive forces over long distances.

The outer electrode can have areas with essentially constant layer thickness, which has the benefit that the outer electrode can be applied b means of a screen-printing process.

In an advantageous embodiment of the electrical multi-layer component, the outer electrode contains copper, enabling the material costs for the component to be reduced.

Furthermore, it is beneficial if the ceramic layers are piezoelectrically active. This is beneficial because the electrical multi-layer component can be used as a piezo actuator.

A piezoelectric effect is obtained, for example, through the use of a ceramic based on lead zirconate titanate.

The indentations can run in the form of troughs, with the troughs extending along a longitudinal axis. The projection of these longitudinal axes on the lateral face of the stack of stratified ceramic layers or internal electrodes on the side of the outer electrode intersects the internal electrodes at an angle. That guarantees that every internal electrode that runs along the corresponding outer surface of the stack can be contacted.

This means that the angle α takes on a value that is other than 0 and 180°.

It is possible to advantageously arrange a plurality of indentations at equal distances. This has the benefit that the outer electrode is divided uniformly into a plurality of areas, which means a corresponding reduction in the maximum occurring shearing force.

In addition, a plurality of indentations can be distributed uniformly over the layer.

Furthermore, it is also possible to arrange a plurality of indentations in such a way that they form a periodically recurring structure (for example a rhombus or square).

In order to guarantee the function of the indentation as an intended tear point, it is advantageous for the minimum layer thickness at the point of the indentation to be a maximum of 75% of the layer thickness in the area where the layer thickness is essentially constant.

The outer electrode can be applied in the form of a screen-printing paste that contains copper powder.

Applying the outer electrode in the form of a screen-printing paste has the benefit that by using appropriate screen-printing masks; a reliable and uniform arrangement of indentations can be achieved with simple means.

When applying the outer electrode in the form of a screen printing paste or by means of a screen printing process, it is beneficial to be sure that the indentations have a minimum width of 200 μm, since otherwise it is no longer possible to guarantee a defined indentation on the basis of the consistency of the paste or the mesh number used. Smaller indentations can be realized only with increased effort and expense, due to the low viscosity of the screen-printing paste normally used. It would be conceivable, however, to produce indentations with smaller lateral extents by using a more structurally viscous or more thixotropic screen-printing paste.

In addition, a method for producing an electrical multi-layer component is specified that includes the following steps:

a) Production of a base body with a stack of stratified ceramic layers and internal electrodes lying between them, and with an outer electrode placed on a lateral face of the

base body for contacting internal electrodes, which has the form of a layer and in which at least one indentation is provided.

b) Contacting of the outer electrode with a contact element while exerting a shearing load between the outer electrode and the lateral face of the base body.

Normally materials are used for the ceramic layers and the outer electrode whose thermal expansion coefficients differ from each other.

The method for producing the multi-layer electrical component has the advantage that in spite of exerting the shearing load, because of the intended tear points or already existing tears formed by the indentation, the danger of detachment of the outer electrode is reduced.

Despite the use of materials adapted to their particular function with normally differing thermal expansion coefficients for the outer electrode and ceramic layers, the invention allows the contacting of the outer electrode with a contact element to take place by soldering.

When copper is used for the outer electrode and when a PZT ceramic is used for the ceramic layers of the stack, the possibility exists of performing the soldering at a temperature > 200° C, which allows the use of correspondingly high-melting solders.

Such high-melting solders have the advantage that they permit use of the electronic component, for example a piezo actuator, at temperatures of up to 150° C, such as occur, for example, on the combustion engine of a motor vehicle.

The invention will now be explained in greater detail on the basis of exemplary embodiments and the matching figures.

Figure 1 shows an example of an electric multi-layer component in schematic cross-section.

Figure 2 shows an additional embodiment of an outer electrode.

Figure 3 shows different profiles of shearing forces with a continuous and an interrupted outer electrode.

Figure 4 shows indentations in the form of troughs.

Figure 5 shows indentations arranged along a regular grid.

Figure 6 shows an example of an electrical multi-layer component with an intermediate layer formed at the edge of the base body.

Figure 1 shows a piezo actuator, with a base body 1 that includes a stack la of stratified ceramic layers 2 and internal electrodes 3 lying between them. The piezo actuator or the base body 1 is shown lying down. The base and cover surface of stack la are thus located on the right and left sides of Figure 1, respectively. The internal electrodes 3 reach alternately to the upper edge and to the lower edge of stack 1a. Along

passive zones 13 only every second internal electrode 3 is present, so that in this zone only a very small deflection of the piezo actuator results when an electrical potential is applied between the internal electrodes 3 emerging from the lower end of stack 1a and those emerging from the upper end of stack 1a.

An outer electrode 5 is placed on the upper lateral face 4 of the base body 1, for contacting internal electrodes 3. The outer electrode 5 has indentations 6. It can be seen from the detailed view of Figure 1 that the indentations 6 are in the form of local minima of the layer that determines the form of the outer electrode. Within the indentation 6, the layer thickness d is a minimum of d_{min}. In addition, the outer electrode 5 has areas of essentially constant layer thickness d, which means that in these areas the layer thickness d varies by less than 10%. It can also be seen from the detail of Figure 1 that the indentation 6 has a width b, which should not fall below a certain minimum dimension when the outer electrode is applied by a screen printing process, since otherwise the normally used screen printing processes have to be specially adapted, for example by using a more structurally viscous screen printing paste.

The minimum layer thickness d_{min} in the area of indentation 6 should be no more than 75% of the layer thickness d of the outer electrode 5, since otherwise the function of the intended tear point is no longer guaranteed.

An additional exemplary embodiment is described in Figure 2. There, the outer electrode 5 on the lateral face 4 of the base body 1 is interrupted at the point of the indentation 6. This means that the layer thickness d is zero in the area of the indentation 6. This embodiment has the advantage that under a thermal load, for example, the outer electrode 5 does not have to tear only at the location of the intended tear point, but that the interruptions already exist and the maximum occurring shearing force is already inherently reduced (see also the explanation for Figure 3).

Figure 3 explains the effect that interrupting an external electrode 5 has on the shearing forces that occur in the case for example of a deflected piezo actuator. To this end, the base body 1 of a piezo actuator is shown schematically in Figure 3. The deflection of the piezo actuator is represented schematically by double arrows. On the top side of base body 1, a continuous outer electrode 5a is shown. On the bottom of the piezo actuator or of base body 1, an outer electrode 5b interrupted by the indentation 6 is shown schematically in cross section. If one considers the same tensile stress for the upper outer electrode 5a and the lower outer electrode 5b (indicated by the two double arrows), this produces the profile shown below Figure 3 for the qualitative profile. Curve 10 describes the profile of the shear stress S as a function of the longitudinal coordinate z of base body 1 for the continuous outer electrode 5a. On the other hand, curve 11 describes the profile of the shear stress S as a function of the longitudinal coordinate z of base body 1 for the interrupted outer electrode 5b.

Since the tensile or compressive stresses add up over a longer distance in the case of the outer electrode 5a, the greater maximum shear load also arises for the outer electrode 5a, identified in Figure 3 as S_2. In the case of the interrupted outer electrode 5b, the tensile or compressive stress can only add up over a shorter distance, which leads to the fact that a smaller maximum shearing load S_1 results, as can be seen from the profile of curve 11. This lower maximum shear stress results in a reduction of the danger that the outer electrode 5b will tear off under a mechanical load, for example by pulling on wires connected to the outer electrode 5b, or also by a plurality of deflections of the piezo actuator.

A favorable minimum width b is around 200 μm. A typical layer thickness d producible by screen printing processes is around 15 - 25 μm.

Figure 4 shows indentations 6 in an outer electrode 5 in the form of troughs running along a longitudinal axis 7. Figure 4 is a top view of an example of an outer electrode 5. In addition, Figure 6 shows lines 8 that symbolize the profile of the internal electrodes 3 corresponding to Figure 1. The longitudinal axes 7 run essentially parallel to each other and intersect the lines 8 at an angle α, which is other than 0° and 180^0. The result is that every second internal electrode, represented by lines 8, is contacted by areas 14 with an essentially constant layer thickness d of the outer electrode 5. This makes it possible to ensure that every second internal electrode 3 is contacted by the outer

electrode 5 or by areas 14 with an essentially constant layer thickness of the outer electrode 5.

Figure 5 shows a top view of another exemplary embodiment for a structured outer electrode 5. Here indentations in the form of circles are provided, which form a square grid.

When the outer electrode 5 is applied in the form of a screen printing paste, it is usual to use a screen printing paste that contains glass frit. This glass frit is used to improve the mechanical bonding of the outer electrode 5 to the base body 1. Depending on the glass frit used and depending on the ceramic used, or depending on the setting of additional process parameters, it can occur that the glass frit forms an intermediate layer 9 lying between the outer electrode 5 and the edge of the base body 1, which intermediate layer 9 is interrupted in the area of the internal electrodes 3. When considering the problem of the shearing off or separation of the outer electrode 5, the intermediate layer 9 of glass frit must be allocated to the base body 1, as can be seen from Figure 6. Detachment processes take place preferably between the outer electrode 5 and the intermediate layer 9.

Figure 6 also shows two contact elements 12, which may be in the form, for example, of thin wires, and which are connected to the outer electrode 5 by soldering. When a PZT ceramic is used for the ceramic layers that has a thermal expansion

coefficient of 1.5 – 2.0 x 10^{-6} m/mk, and when using an outer electrode 5 of copper with a thermal expansion coefficient of 19 x 10^{-6} m/mk, providing the indentations 6 results in the possibility of performing the soldering of the contact elements 12 at a temperature of around 300° C, which permits the use of high-melt solders, for example Pb-based solders.

For the glass frit it is possible, for example, to use a combination that contains lead oxide, silicon oxide, boric oxide and possibly additional components.

The present invention is not limited to use in piezo actuators, but is applicable in principle to all multi-layer components, for example also to capacitors.